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Maps of area of habitat for Italian amphibians and reptiles

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Abstract

Planning conservation actions requires detailed information on species' geographic distribution. Species distribution data are most needed in areas hosting unique or endangered biodiversity. Italy is one of the European countries with the highest levels of herpetological diversity and endemism and is home to several threatened species of amphibians and reptiles. Information on the distribution of species' habitats can help identify sites where the species is most likely to thrive, as viable populations depend on it. Area of Habitat (AOH) maps reveal the distribution of the habitat available to the species within their geographic range. We produced high resolution, freely accessible global area of habitat maps for 60 species of reptiles and amphibians distributed in Italy, which represent 60% of all Italian amphibian and reptile species. We validated a total of 44 AOH maps through a presence-only based evaluation method, with 86% of these maps showing a performance better than expected by chance. AOH maps can be used as a reference for conservation planning, as well as to investigate macroecological patterns of Italian herpetofauna. Furthermore, AOH maps can help monitoring habitat loss, which is known to be a major threat to many reptile and amphibian species in Europe.

Keywords

Area of occupancy, extent of habitat, herpetofauna, Italy, IUCN Red List

Introduction

Species distribution maps are extensively used in ecology- and conservation-related studies. Accurate maps are needed to investigate large scale patterns and processes of species distribution, as well as to develop effective conservation strategies. However, data on species distribution are often incomplete, inaccurate or do not have the resolution and accuracy that is often required for conservation planning (Rondinini et al. 2006; Ball-Damerow et al. 2019).

Area of habitat (AOH) maps are spatial representations of the habitat available to a species within its distribution range (Brooks et al. 2019). They can be used to exclude areas within the distribution range that do not represent a viable environment for the species and, thus, are less likely to host species' populations. AOHs are produced by combining the range of a species with a map of the habitat which is found within the altitude limits of the species (Brooks et al. 2019). In order to map the habitat, land cover classes are linked to species' habitat requirements (Rondinini et al. 2011; Lumbierres et al. 2021). AOH maps have been produced in several studies for multiple vertebrate taxa (Rondinini et al. 2011; Ficetola et al. 2015), enabling broad-scale assessments of conservation priorities (Hanson et al. 2020; Williams et al. 2020). AOH have also been included in the Global Standard for the Identification of Key Biodiversity Areas (IUCN 2016), as an effective method to assess the population size of a species across its range. A first set of AOH maps for amphibian species on a global scale was produced by Ficetola et al. (2015). In that study, habitats were linked to the global land cover categories of GlobCover v. 2.1 (IONIA 2009), which has a resolution of approximately 300 m at the Equator. So far, the AOH approach has not been implemented for reptiles, for which the distribution range of many species have been published only recently (Roll et al. 2017).

One of the most comprehensive databases for global distribution ranges of terrestrial vertebrates is the International Union for Conservation of Nature (IUCN 2021) Red List, although not all taxa are equally represented (Cardoso et al. 2011; Verde Arregoitia 2015; Cazalis et al. 2022). For amphibians and reptiles, the database is still incomplete although nearly all the European species are covered. Species range maps are freely accessible through the IUCN Red List portal (www.iucnredlist.org).

Italy is one of the most species-rich countries for amphibians and reptiles in Europe (Cox and Temple 2009; Silero et al. 2014), hosting approximately 101 species (Sindaco and Razzetti 2021) that correspond to one-third of all European species of amphibians and reptiles (Speybroeck et al. 2020), although the exact numbers may change according to the taxonomy of a few species, of which the status is not unanimously accepted by the scientific community due to the complexity of their evolutionary history. Regardless of their status, some endemic evolutionary significant units, such as *Vipera walser* and *Bombina pachypus*, are of high conservation concern and require special conservation efforts (Canestrelli et al. 2013; Ficetola et al. 2020). Italy is home to seven amphibian and two reptile species living in terrestrial and freshwater habitats, which are listed as threatened by the IUCN Red List (IUCN 2021). Furthermore, the

Italian Peninsula along with its islands is an important centre of endemism of European herpetofauna (Silero et al. 2014; Ficetola et al. 2018).

We developed high resolution global AOH maps for 25 amphibians and 35 reptiles occurring in Italy, based on the IUCN distribution ranges. We validated AOH maps for 21 amphibians and 23 reptiles using a presence-only based evaluation method. Although the main focus of this study was to map the habitat distributions of the species in Italy, providing global area of habitat maps for the species allows estimating habitat availability within their global range. This information is particularly important in the process of identifying Key Biodiversity Areas (KBA) for a target species (IUCN 2016). These AOH maps can be used to investigate spatial patterns and distribution of herpetological diversity in Italy, as well as to support conservation actions and protected areas planning.

Materials and methods

Species occurrence points

Species occurrence points registered in Italy between 2000 and 2021 were obtained from the Global Biodiversity Information Facility (GBIF.org 2021). GBIF occurrence datasets DOIs for each species are available in Suppl. material 3: Appendix 3. Only iNaturalist Research-grade observations were retained. Research-grade observations represent the highest quality occurrence data on the iNaturalist database and therefore, the most reliable. In order to be accepted as Research-grade, an observation must include the date of collection, a picture or sound recording and GPS coordinates (https://www.inaturalist.org). We did not filter data for georeferencing accuracy. All occurrence points not falling within the species IUCN range were removed, as well as outliers and duplicate records. The processed dataset was then implemented in the validation process described in the last paragraph of this section.

Area of habitat maps

Area of habitat (AOH) maps were produced, based on a set of species distribution ranges on a global scale. Global distribution ranges were obtained from the IUCN Red List database (IUCN 2020). We retrieved a total of 25 amphibian and 34 reptile distribution ranges of species occurring in Italy, which represent approximately 60% of all Italian amphibian and reptile species (Sindaco and Razzetti 2021). All species live in terrestrial/freshwater habitats, excluding cave habitats. An additional range was added for *Vipera walser*, a recently described endemic taxon of viper which only occurs in a narrow area in northern Italy (Ghielmi et al. 2016; see also Doniol-Vacroze et al. 2021 for additional taxonomic discussion) The range of *V. walser* was obtained from Ficetola et al. (2020). As a taxonomic reference, we relied on two databases: AmphibiaWeb (amphibiaweb.com) for amphibian species and The reptile Database (Uetz et al. 2021,

http://www.reptile-database.org) for reptile species. We selected species for which we could retrieve the distribution range from the IUCN Red List database. Additionally, the species' taxonomy had to be accepted by the referenced database.

Species were linked to their natural habitat using Copernicus Global Land Service Land Cover (CGLS-LC100) 2019 classes as a habitat surrogate. Species-Habitat associations and altitude limits were based on monographs on the biology of target species (Sindaco et al. 2006; Lanza et al. 2007; Corti et al. 2011), while for *V. walser*, we used data in Ficetola et al. (2020). CGLS-LC100 is a global map of land cover produced by the European Union's Earth observation programme, freely accessible at the official programme website (land.copernicus.eu). A link to a detailed description of all land cover classes is available in Suppl. material 3: Appendix 3. We selected 13 land-cover classes available on the geographic surface of Italy that could be classified as habitat or lack of habitat for the species. The selected categories are available in Suppl. material 4: Appendix 4. The map is available in a standard latitude/longitude grid (EPSG:4326), ellipsoid WGS 1984. The grid resolution is 1°/1008, approximately 100 m at the Equator. We compiled a binary classification to link species habitat to land-cover classes. A score of either 1 or 0 was assigned to the species, according to whether a specific category represents a viable habitat for the species or not, respectively. Furthermore, we compiled altitude limits (minimum and maximum) for each species. As altitude limits of species distributions can vary according to the local environmental and geological conditions, we implemented altitude-limit categories. Maximum altitude limits were assigned with a minimum of 0 m, progressing in steps of 200 m up to 1800 m. For species which can be found above 1800 m, we set the maximum altitude limit to 2500 m, except for *Rana temporaria* for which we assigned a limit of 2800 m, based on recently reported altitude limits for the species (Tiberti and von Hardenberg 2012).

In order to generate the AOH maps, we followed the procedure presented in Rondinini et al. (2011) and Lumbierres et al. (2021). First, the CGLS-LC100 map was combined with altitude information to produce a base map. Each raster cell in the base map holds information on the land-cover class and altitude data. The first three digits of cell values represent land cover and the three last digits, the altitude in m/10. Altitude data were obtained from the Shuttle Radar Topography Mission (USGS EROS Archive 2019) map, which has a resolution of approximately 30 m. We resampled the altitude map at the resolution of the CGLS-LC100 using aggregation. The base map can be reclassified in order to retain only areas which meet species' habitat requirements. Species-habitat association scores and altitude limits were combined to produce reclassification files for each species in R version 4.0.3 (R core team 2021). The R code to produce reclassification files is available in Suppl. material 1: Appendix 1. First, in GRASS GIS version 7.8.5 (GRASS Development Team 2020), we used IUCN species ranges to mask the area of the base map which is found out of the species range. Then, the base map was filtered according to reclassification files. Only land cover areas that met the species' habitat requirements were retained to produce the area of habitat map. Each pixel in the base map belongs to a single class of the land cover. Therefore, the pixel must necessarily belong to one of the classes which are linked to species' habitat in order to be retained in the AOH map. We assigned a value of 1 to each raster cell classi-

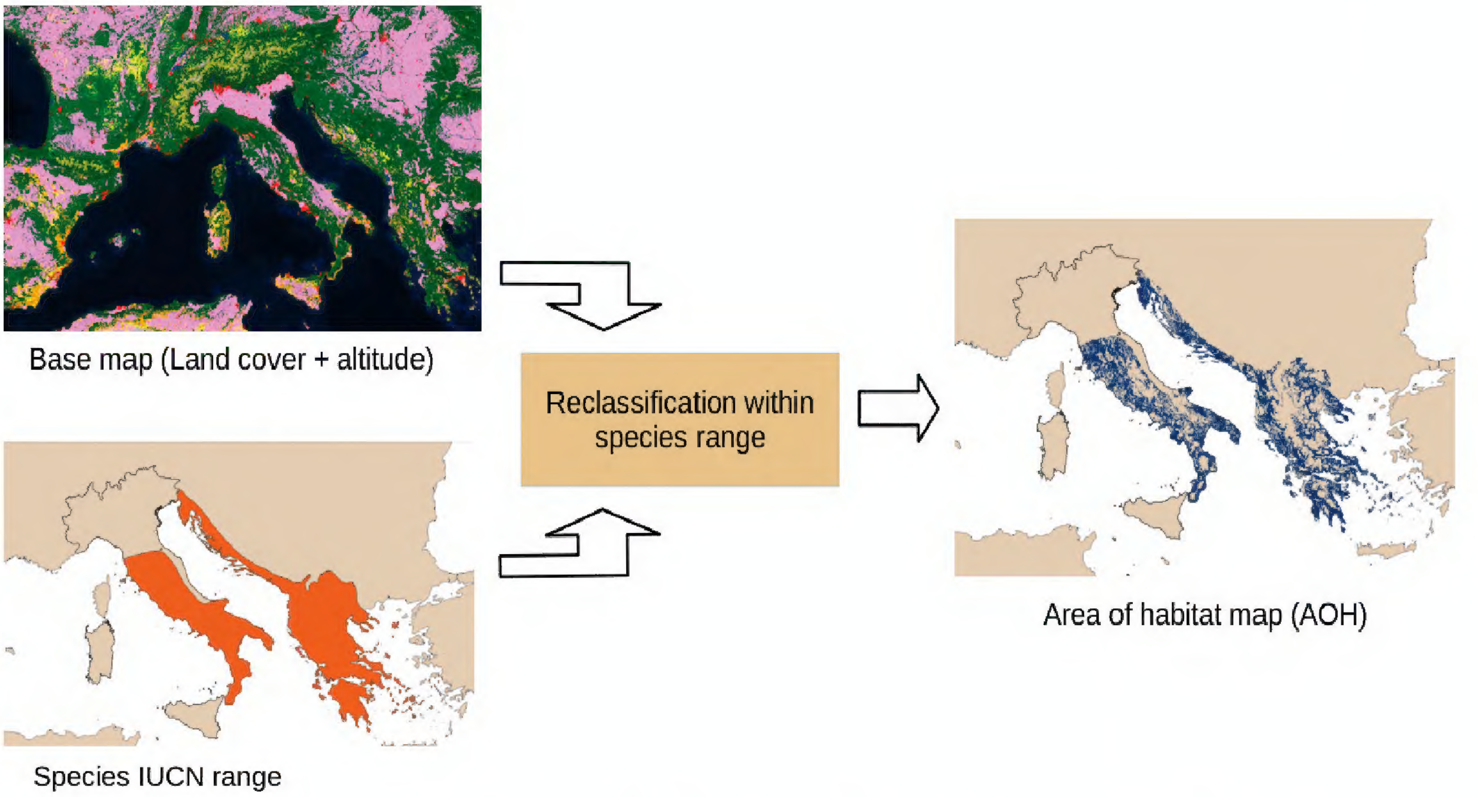

Figure 1. An explanatory scheme of the workflow used to produce the area of habitat maps.

fied as available habitat for the species. For each cell falling within the range of the species, but not matching the species habitat requirements, the assigned value was 0. All cells not falling within the species range were classified as NA. An explanatory scheme of the methodology used to develop the AOH maps is shown in Fig. 1. The complete GRASS code to produce the AOH maps is available in Suppl. material 1: Appendix 1.

AOH validation

AOH maps were validated for 44 species within the Italian distribution range, as the species-habitat association scores are based on knowledge of species' habitat requirements in Italy. We used a hypergeometric distribution approach, as suggested by Jiménez and Soberón (2020) and implemented in Dahal et al. (2021). Based on a defined number of occurrence points, the hypergeometric distribution describes the probability of a point falling within the area of habitat of a species. This method allows testing for accuracy of species distribution models through the use of presence-only data. The method is based on point prevalence. After defining a confidence interval, the hypergeometric test calculates the upper and lower limits of the function, based on point prevalence and model prevalence. If the point prevalence exceeds the upper limit of the hypergeometric function, the model can be considered better than random. The model prevalence is the proportion of raster cells within the distribution range which were classified as available habitat for the species (Dahal et al. 2021). The point prevalence represents the proportion of occurrence points out of the total number of occurrences within the range of the species falling inside the available habitat (Dahal et al. 2021). For maps' validation, we used the dataset of occurrence points obtained from GBIF. We only validated AOH maps of the species for which we could retrieve at least five occurrence points falling within their IUCN range in Italy. This threshold was

implemented in previous works to evaluate AOH maps (Ficetola et al. 2015). Before testing for model performance, we applied a buffer of 150 m to the occurrence points. The buffer accounts for miscalculations due to possible inaccuracy of the occurrence records (e.g. limits of the GPS device to record coordinates), as well as for errors due to the resolution of the AOH maps (100 m). Subsequently, model prevalence and point prevalence were calculated to test the model performance. The confidence interval was set to 95%. The full R code used for the analysis with comments on settings and parameters is available in Suppl. material 1: Appendix 1. A summary of the model performance test, including the number of points used for each species, is available in Suppl. material 2: Appendix 2. The complete dataset of occurrence records which were used to validate the AOH maps is included in Suppl. material 3: Appendix 3.

Results and discussion

AOH maps

A total of 60 Area of Habitat maps were produced. The mean percentage of area of habitat cover within the range of the species is 48% for amphibians and 44% for reptiles, showing that AOH maps represent an important refinement of the original distribution range of the species. However, for some species, the habitat extent is still overestimated due to the resolution and limitations of land-cover data. For instance, this can be true for semi-aquatic species, as we focused on the terrestrial habitat. The habitats where amphibians breed (e.g. small ponds, vernal pools...) are too small to be detected by remote sensing. Therefore, in this case, the habitat extent should be considered an upper estimate of the available terrestrial habitat; the actual estimate is probably lower because only terrestrial habitats that are spatially connected to suitable breeding sites can be occupied by adults (Becker et al. 2007). A complete list of the species for which AOH maps were produced can be found in Table 1. The 60 available maps include 25 amphibians and 35 reptile species occurring in Italy, corresponding to 60% of all Italian species of reptiles and amphibians (Sindaco and Razzetti 2021). An example of an AOH map produced for the four-lined snake *Elaphe quotuorlineata* is shown in Fig. 2.

A total of 44 AOH maps were validated, while for 16 species, we could not retrieve a sufficient number of occurrence points (≥ 5) to test the AOH model performance. All hypergeometric test results are listed in Suppl. material 2: Appendix 2. Out of the 44 validated AOH maps, the performance of 38 (86%) was significantly better than expected under randomness as the point prevalence exceeded the upper limit of the confidence interval (Jiménez and Soberón 2020). The remaining six maps showed a point prevalence percentage remaining below the upper limit of the confidence interval, with five of them having a point prevalence which exceeded the model prevalence. Four of the six AOH models which did not perform better than expected by chance were assessed with a number of occurrence points equal to 11 or lower.

Table 1. The table shows the list of species for which a global AOH map was produced, together with their IUCN Red List status. Information on their performance under validation is indicated as better than random (BTR) or not better than random (NBTR).

Species	Model performance	IUCN RL status	Species	Model performance	IUCN RL status
Bombina pachypus	**BTR**	**EN**	*Chalcides chalcides*	/	**LC**
Bombina variegata	**BTR**	**LC**	*Chalcides striatus*	/	**LC**
Bufo bufo	**BTR**	**LC**	*Coronella austriaca*	**BTR**	**LC**
Bufotes viridis	**BTR**	**LC**	*Coronella girondica*	**BTR**	**LC**
Discoglossus pictus	**BTR**	**LC**	*Elaphe quatuorlineata*	**BTR**	**NT**
Discoglossus sardus	**NBTR**	**LC**	*Emys trinacris*	/	**DD**
Euproctus platycephalus	/	**EN**	*Euleptes europaea*	/	**NT**
Hyla arborea	/	**LC**	*Hemidactylus turcicus*	**BTR**	**LC**
Hyla intermedia	**NBTR**	**LC**	*Hierophis viridiflavus*	**BTR**	**LC**
Hyla sarda	**BTR**	**LC**	*Iberolacerta horvathi*	/	**NT**
Ichthyosaura alpestris	**BTR**	**LC**	*Lacerta bilineata*	**BTR**	**LC**
Lissotriton italicus	**BTR**	**LC**	*Malpolon monspessular*	**BTR**	**LC**
Lissotriton vulgaris	**BTR**	**LC**	*Mediodactylus kotschyi*	**NBTR**	**LC**
Pelobates fuscus	**NBTR**	**LC**	*Natrix maura*	**BTR**	**LC**
Pelophylax ridibundus	/	**LC**	*Natrix tessellata*	**BTR**	**LC**
Rana dalmatina	**BTR**	**LC**	*Podarcis filfolensis*	/	**LC**
Rana italica	**BTR**	**LC**	*Podarcis melisellensis*	/	**LC**
Rana latastei	**BTR**	**VU**	*Podarcis muralis*	**BTR**	**LC**
Rana temporaria	**BTR**	**LC**	*Podarcis siculus*	**BTR**	**LC**
Salamandra atra	**BTR**	**LC**	*Podarcis tiliguerta*	**BTR**	**LC**
Salamandra lanzai	**BTR**	**VU**	*Podarcis waglerianus*	**BTR**	**LC**
Salamandra salamandra	**BTR**	**LC**	*Testudo marginata*	**NBTR**	**LC**
Salamandrina perspicillata	**BTR**	**LC**	*Timon lepidus*	/	**NT**
Salamandrina terdigitata	/	**LC**	*Vipera ammodytes*	**BTR**	**LC**
Triturus carnifex	**BTR**	**LC**	*Vipera aspis*	**BTR**	**LC**
Algyroides fitzingeri	**BTR**	**LC**	*Vipera berus*	**BTR**	**LC**
Algyroides nigropunctatus	/	**LC**	*Vipera ursinii*	**BTR**	VU
Anguis fragilis	**BTR**	**LC**	*Vipera walser*	/	**DD**

Relevance of the AOH maps

In Europe, habitat loss has been identified as one of the major threats to many amphibian and reptile species (Cox and Temple 2009; Falaschi et al. 2019). AOH maps can be combined with information on land-use change to evaluate how habitat loss is affecting species distribution (Tracewski et al. 2016), to develop monitoring plans in areas suffering habitat loss and to support conservation actions for threatened species. The produced dataset includes AOH maps for four amphibians and one reptile species which are listed under the threatened taxa in the IUCN Red List (IUCN 2021), as reported in Table 1. Three of the threatened amphibian species are facing population decline due to habitat loss and fragmentation. The dataset also includes AOH maps for five reptile species which are globally assessed as "Near threatened" (NT) in the IUCN Red List (IUCN 2021). Habitat degradation is one of the major threats to four of these

species (IUCN 2021). Knowing where the habitat of a species occurs is also crucial for conservation planning, for instance, in the process of designing new protected areas. AOH maps can be incorporated into the identification of Key Biodiversity Areas, as they can be used to infer population size of a species (IUCN 2016). The AOH maps are based on species' habitat requirements in Italy and were validated within the Italian geographical boundaries, but they also provide an estimate of the distribution of the habitat throughout the whole range of the species. Thus, they can be implemented to apply KBA criteria which rely on this information to detect potential KBAs for amphibians and reptiles in Italy (IUCN 2020). Finally, the AOH maps are a useful tool to investigate general patterns and distributions of herpetological diversity in Italy. They can be used to plan research orientated sampling and fieldwork for target species and to evaluate changes in the habitat available for species if new land-use time series are produced. There are some limitations in the use of AOH maps for conservation, the most obvious one being the resolution of the data. Information on available habitat quantity within the land-cover pixel is missing. Moreover, a binary classification is not optimal, as the habitat quality may vary across the spatial surface. In the future, habitat maps may be improved by including local predictors and landscape predictors, thus providing additional information on habitat availability (Dubos et al. 2022).

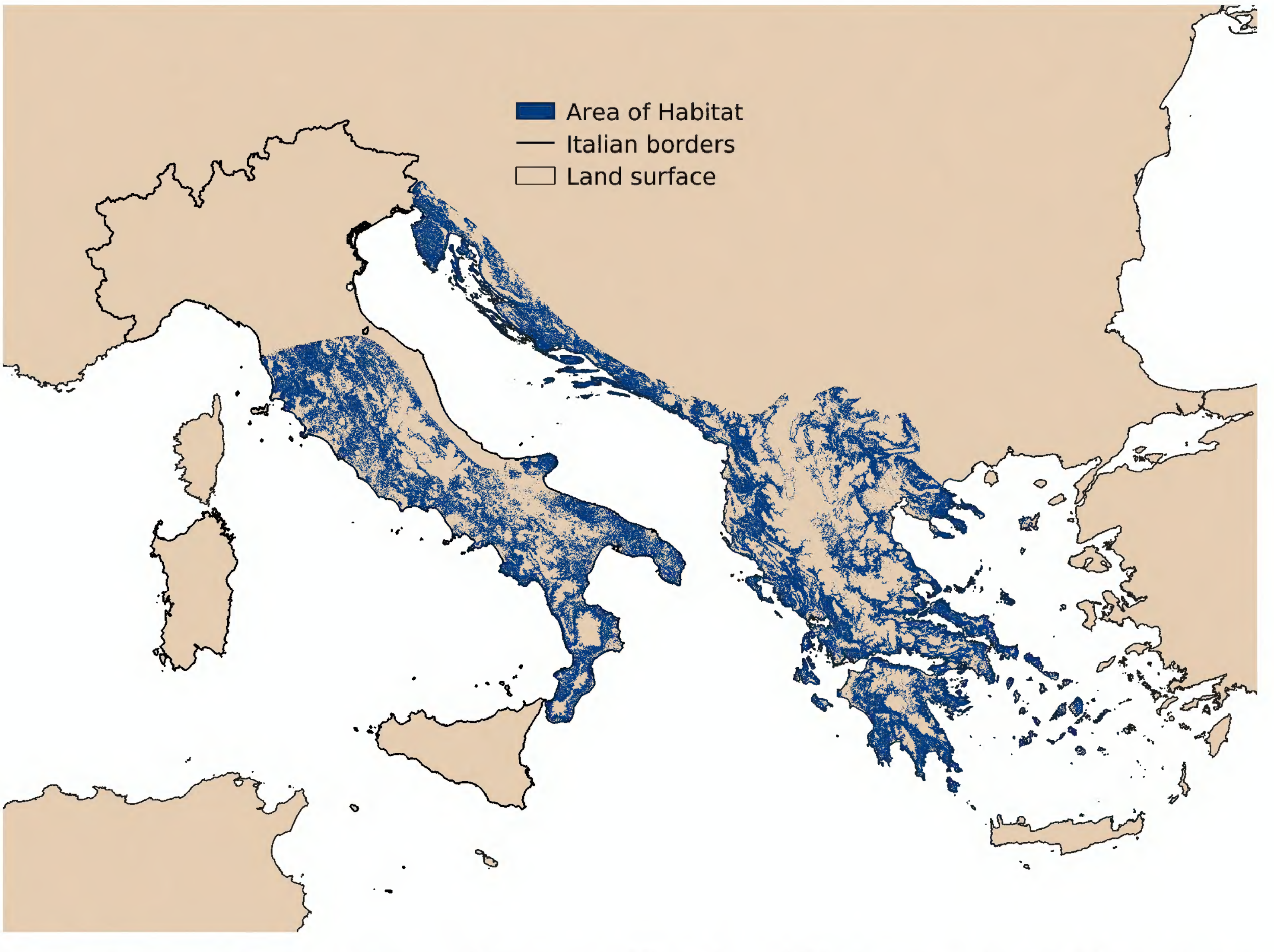

Figure 2. A map showing the area of habitat (AOH) surface of *Elaphe quatuorlineata*. Habitat for the species (blue) is identified within the IUCN global range.

Data availability

All maps are available in GeoTIFF format and are freely accessible in the DRYAD repository: https://doi.org/10.5061/dryad.2547d7ws8.

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Supplementary material 1

Appendix 1

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Data type: pdf file

Explanation note: R code to produce the reclassification files; GRASS code to produce the AOH maps; R code for the hypergeometric test.

Link: https://doi.org/10.3897/natureconservation.49.82931.suppl1

Supplementary material 2

Appendix 2

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Data type: pdf file

Explanation note: Hypergeometric test – model performance – Amphibians and Reptiles.

Link: https://doi.org/10.3897/natureconservation.49.82931.suppl2

Supplementary material 3

Appendix 3

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Data type: pdf file

Explanation note: Species occurrence dataset with DOI for GBIF download.

Link: https://doi.org/10.3897/natureconservation.49.82931.suppl3

Supplementary material 4

Appendix 4

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Data type: excel file

Explanation note: 13 land-cover classes available on the geographic surface of Italy.

Link: https://doi.org/10.3897/natureconservation.49.82931.suppl4